Ka-Band Link Experiment (KaBLE) Description and Preliminary Results

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Abstract

This paper describes the Ka-Band Link Experiment (KaBLE) with the Mars Observer (MO) spacecraft. The objectives of KaBLE are discussed and a comparison using flight tests between X-Band and Ka-Band reception is presented.

1 Introduction

The Ka-band Link Experiment (KaBLE) with the Mars Observer (MO) spacecraft is part of an on-going effort to establish viability of the .34 /32 GHz frequency bands for communication with deep space spacecraft. The overall objective of the experiment is to evaluate for the first time, the performance of a spacecraft to ground communication link (downlink) at 33.7 GHz (Ka-Band) relative to a 8.4 GHz (X-Band) downlink, currently the highest Deep Space Network (DSN) operating frequency. This information will used to design future deep space missions which will operate at Ka-Band.

Figure 1 depicts DSS-13 (R&D station) and DSS-24 (operational station) "ideal Ka-band" with an absolute maximum performance advantage of about 12 dB (based solely on for a 6 dB advantage of Ka-band over X-band assuming spacecraft (s/c) systems are of equal performance. owever, with current s/c flight qualified technology, and equal s/c antennas, the real expected advantage would be only 2.4 dB into DSS-24 with an operational Ka-band capability devised with our current technology, and about 2 dB for the actual DSS-13. Within the next three years, it is expected that the erformance of either of these antennas will improve by about 2 dB. We expect parallel improvements in s/c efficiencies.

2 KaBLE Description

This section presents a technical description of the experiment in the context of the MO mission, as depicted in Fig. 2. The primary engineering objective is to measure and document the performance of Ka-band and X-band downlinks using the same path simultaneo so that an accurate comparison can be made. The second objective is to receive coded telemetry at a data rate of 250 bits/sec. A third objective is to measure the s/c to earth distance using Ka-band downlink in conjunction with X-band ranging.

The Ka-band downlink on MO is generated directly from the X-band downlink at the High Gain Antenna (HGA) as shown in Fig. 3. A 14 dB coupler diverts 28 dBm (about 3%) to a ×4 frequency multiplier producing a 14.3 dBm Ka-band signal. This is conducted via waveguide to a feed at the focal point of the 28 cm diameter subreflector that serves as the Ka-band antenna. The experiment design makes use of the fact that the Ka-band hase modulation index is 4 times the X-band modulation index. The telemetry experiment was planned at a rate of 250 bps in January 5-18, 1993 when Ka-band is first enabled as this is the only time the Ka-band link margin will e sufficient. A link analysis is shown in Fig. 4.

As part of the experiment, all measurements and events wil be time- agged relative to the station Frequency and Timing Subsystem (FTS) so that they can be retrieved and cross-referenced chronologically. The following parameters have been measured and recorded at intervals of 1 minute (± 1 msec), except as noted:

Atmospheric temperature, pressure and humidity

Wind speed and direction

Rain and rain rate!

Water Vapor and droplets in antenna beam

Antenna physical temperature

Antenna pointing angles and pointing errors

Subreflector position

System noise temperature at X and Ka- band

Carrier SNR at X and Ka

Symbol SNR at X and Ka (only for 250 bps)

Ranging delay difference X vs. Ka-band

Start and end of pass (per occurrence)

Start of acquisition /reacquisit ion (per occurrence)

Times of carrier, subcarrier and symbol lock (per occurrence)

Times of loss of lock (per occurrence)

Ka and X-band spectra (as required)

The following parameters were computed:

Received carrier at X and Ka-band

Total signal power at X and Ka-band

Ratio of Ka-band to X-band carrier SNR and total power atio

X-band vs. Ka-band carrier phase differentials

Doppler residuals (Ka-band at DSS-13 vs X-band at DSS- 5)

Bit error rate at l{a-bane] vs. X-band

Antenna gain vs. elevation vs. weather parameters

Antenna pointing errors vs. elevation vs. weather

A Data Handling Terminal (1)11'1') has been provided as the KaBLE user interface to the station. The DHT provides interfaces with two Advanced Receivers (ARX's) and the station monitor and control (M & C) subsystem. The software in the DHT accomplishes data acquisition, processing, plotting, recording, retrieval, manipulation, and display requirements.

3 KaBLE Experiment Results

The KaBLE system diagram is shown in Fig. 5 where the microwave subsystem contains the Ka-band and X-band low noise amplifiers (LNA's) followed Ly downconversion to the 200-300 MHz range. The Ka and X-band intermediate frequency (IF) signals are then distributed through the IF distribution assembly to various subsystems that include a multi-tone receiver, a Doppler tuner, two advanced receivers and two total power radiometers. The Doppler tuner operates only on the Ka-band signal as the latter experiences more Doppler shifts, The Doppler tuner uses frequency predicts to remove most Ka-band Doppler rate so that the demodulation process is easier. The multi-tone receiver operates 011 the carrier components and uses information provided by the X-band signal to lock and demodulate the 1{ a-band signal even for extremely weak scenarios. The ARX's output soft symbols which are then decoded to obtain the bits. The two Lit streams (from X and Ka) are then compared in the DHT to provide a Bit Error Rate (BER) measurement on the Ka-band signal assuming that the X-band signal is ideal (which is reasonable due to the high symbol SNR). Figure 6(a) depicts the received P_T/N_0 in dB-Hz from the time the HGA is deployed (which is 100 days after launch). A minimum of 29 dB-Hz is required to receive a 25(I bps telemetry, which is possible for the first 15 days only. Figure 6(b) shows the telemetry margin (in dB) as a function of days from launch. With an EIRP of 49.5 dB and elevation angle of 30 deg, a positive telemetry margin is available for about 15 days only.

The first few days of the experiment experienced an extremely unfavorable whether during which the X-band signal was observed but not the Ka-band signal. With Letter weather and after last minute debugging in the system configuration, both the, X and Ka band signals were received and tracked simultaneously. Telemetry was received only for one day at Ka-band

and decoded successfully. Figure 7(a) and (b) depict the X and Ka-band carrier in dB-Hz as a function of time on January 8th, 1993. Note the. X-band signal was fading during that time period due to pointing problems from the spacecraft. During that same period, the Ka-band signal was lost as expected. The X-band signal was about 55 dB-Hz while the Ka-band signals was in the range of 1 O-1 5 dB-Hz. During that same period, the difference between X-b and received frequency and one fourth of Ka-band received frequency is shown in Fig. 8 which clearly indicates a small differen ce when both signals are tracked. Figure 9 (a) and (b) depicts the received P_c/N_0 in dB-Hz for both X and Ka-band signals on January 1 6th, 1993 and the relative frequencies as observed by the Al{X's. The measurements agree wc]] with the predicts and the Ka-band signals looked stationary to the ARX as most Doppler was removed by the 1)oppler tuner. Figure 10 (a) and (b) depict P_c/N_0 in dB-Hz for both X and Ka-band for the first 9 days of the experiment. Note the irregularity in the Ka-band sig nal P_c/N_0 due to the weather.

As for the telemetry reception, that was performed on January 17th, 1993 with total received Ka-band power as depicted in Fig. 11. Only few hours of telemetry was received when the P_T/N_0 was about 28 dB-Hz. The effective E_b/N_0 is depicted in Fig. 12 as a function of time. From 6 to 9 hours (UTC), E_b/N_0 was between O and 1 dB. in addition, Fig. 12 shows the elevation angle and system temperature of both X and Ka-band signals. Finally, the BER measurements arc depicted in Fig. 13 as a function of E_b/N_0. the measurements agree well with the simulations for E_b/N_0 between 0 and 1 dB.

4 Conclusion

For the first time in the history of the DSN, a Ka-band signal has been received and demodulated from a deep space spacecraft. The carrier tracking measurements agree well with predictions. As for telemetry detection, not enough data was collected to confirm, with high con fidence, the models. But the little data collected agrees well with predictions.

REFERENCES

1. J. W. Layland, *Draft Ka-band Thrust Paper*, Interoffice Memorandum (3300-92-342), December 10, 1992

2. S. A. Butman, J. G. Meeker, *Ka-Band Link Experiment Plan*, JPL D-8799, August 1991.

ACKNOWLEDGEMENT

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Figure 1. Ka-band Advantage over X-band.

Figure 2 KaBLE Concept.

Figure 3. Mars Observer KaBLE Spacecraft Equipment.

Figure 4 ink Design Control Table.

Figure 5.)SS-13 KaB E System Diagram.

Figure 6. KaBLE Kink Profile.

(a) Received P_T/N_0, dB-Hz.

(b) Mean Telemetry Margin, d

Figure 7. Received SNR of X-band and Ka-band Carrier Signal from Mars Observer

(a) X-band P_c/N_0, dB-Hz.

(b) Ka-band P_c/N_0, dB-Hz.

Figure 8. Difference between X-band and 1/4 Ka-band received frequencies.

Figure 9. Received signal on January 6th, 1993.

(a) Carrier P_c/N_0, dB-Hz.

(b))oppler tuned frequency.

Figure 10. Three-dimensional plot of Carrier SNR's.

(a) Ka-band.

(b) X-band.

Figure 11. Ka-band received power during telemetry demonstration.

Figure 12. Ka-band E_b/N_0 and T_{op} vs. time.

Figure 13. Ka-band telemetry decoder performance.

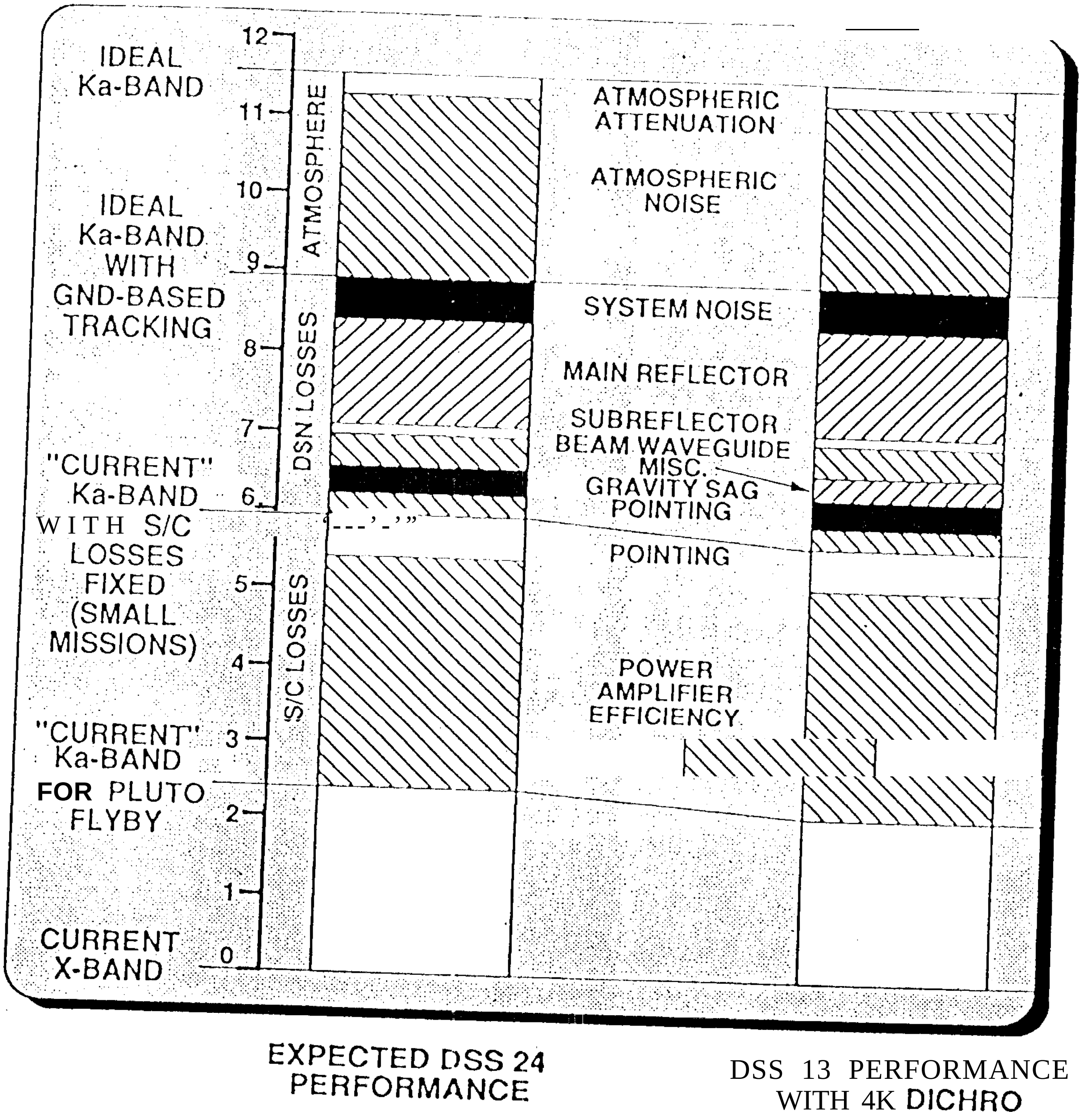


Figure 1. Ka-band Advantage over X-band.

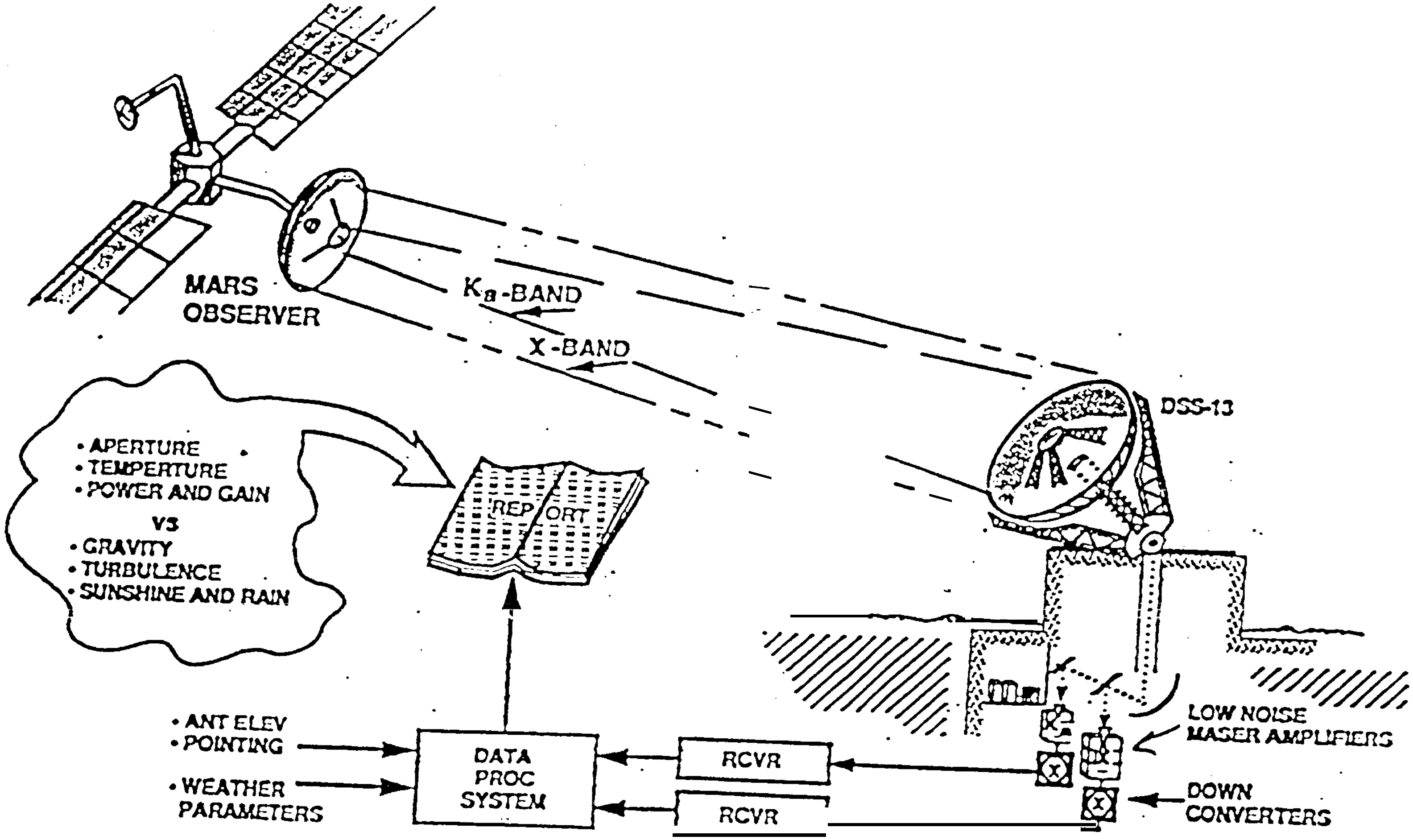
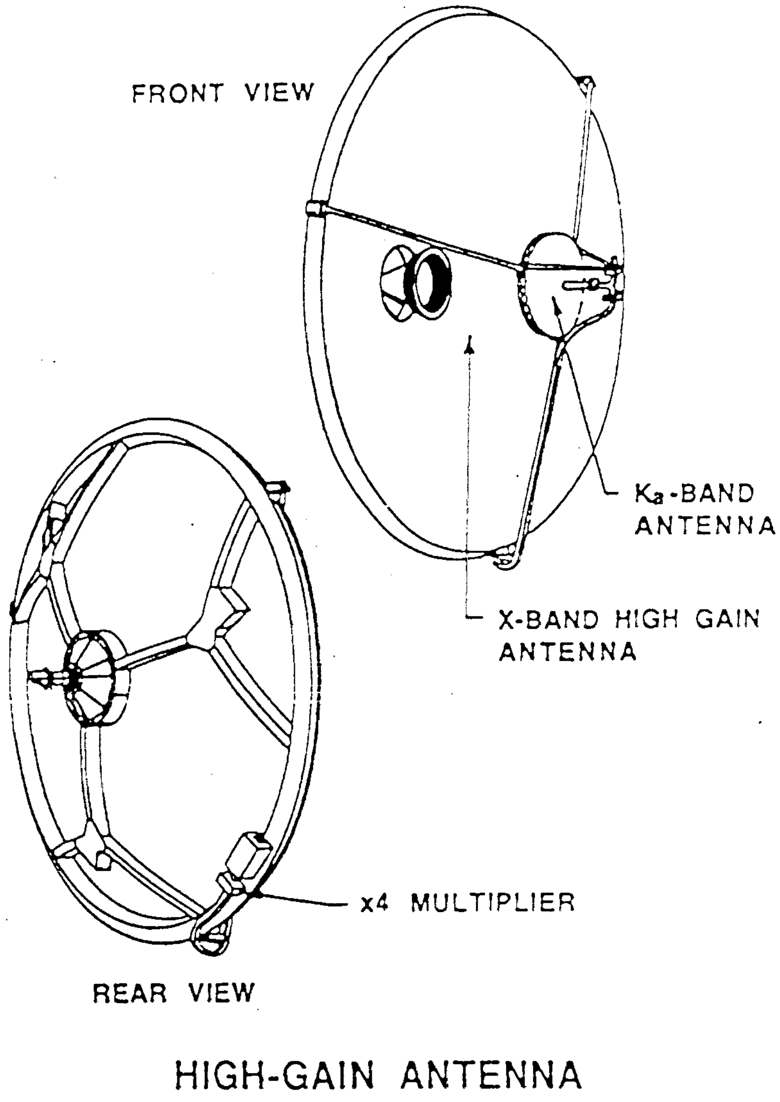


Figure 2 KaBLE Concept.



	X-BAND	K_a-BAND
• DIAMETER, m	1.5	0.28
• 1dB BEAM, deg	0.9	1.3
• GAIN, dB	40.2	37.0
• POWER, dBm	46.5	14.3
• CIRCUIT LOSS, dB	-3.6	-1.5
○ POINTING LOSS, dB	-0.9	-0.5
• EIRP, dBm	82.2	49.3

BLOCK DIAGRAM

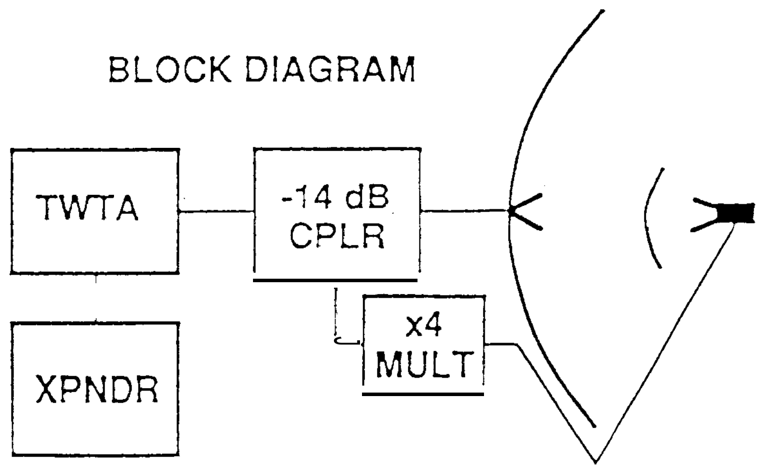


Figure 3. Mars Observer KaBLE Spacecraft Equipment.

	X-BAND		Ka-BAND	
DOWNLINK FREQUENCY (GHz)	8.417716050		33.67086420	
SPACECRAFT PARAMETERS	**MEAN**	VAR	MEAN	VAR
RF POWER OUTPUT (dBm)	46.53	.0171	14.3	.1013
CIRCUIT LOSS (dB)	-3.66	.0202	-1.5	.0224
HGA GAIN (dBi)	40.20	.0267	37.0	.0067
POINTING LOSS (dB)	-0.85	.0075	-0.5	.0038
EIRP (dBmi)	82.22	.0715	49.3	.1342
SPACE **LOSS(@1AU) (dB)**	-274.45	.0000	-286.5	.0000
GROUND SYSTEM PARAMETERS (DSS 13 AT 50 DEG EL, 90% WEATHER)				
ATMO. ATTENUATION (dB)	-0.00	.0000	-0.3	.0004
ANTENNA GAIN (dBi)	68.11	.0056	77.9	.1204
SYSTEM NOISE TEMP(-dBK)	-14.00	.0099	-15.3	.0267
GND, STA & COSMIC 22K			22K	
ATMOSPHERIC 3K			17K	
G/T (dBi/K)	54.11.	.0155	61.7	.1475
POINTING LOSS (dB)	-0.10	.0000	-0.5	.0017
PLRZN & CKT LOSS (dB)	-0.01.	.0003	-0.2	.0004
BOLTZMANN CNST (-dBm/K/Hz)	29-8L6.Q	.0000	198.6	.0000
PT/No (dB-Hz) **@ 1AU**	60.37	.0873	22.4	.2838

At the end of the Telemetry Experiment Jan 18 1993 at 0.37 AU

	X-BAND		Ka-BAND	
PT/No =	69.00	.0873	31.0	.2838

At Solar Conjunction Dec 27 1993, at 2.45 AU

	X-BAND		Ka-BAND	
PT/No =	52.59	.0873	**14.6**	.2838

The above must be corrected for lower DSS 13 elevation and Sun effects which increase system temperature to an estimated 100K at X-band and 110k at Ka-band (TBD VARIANCE), so that

	X-BAND		Ka-BAND	
PT/No =	46.59	TBD	10.1	TBD

Figure 4. Link Design Control Table.

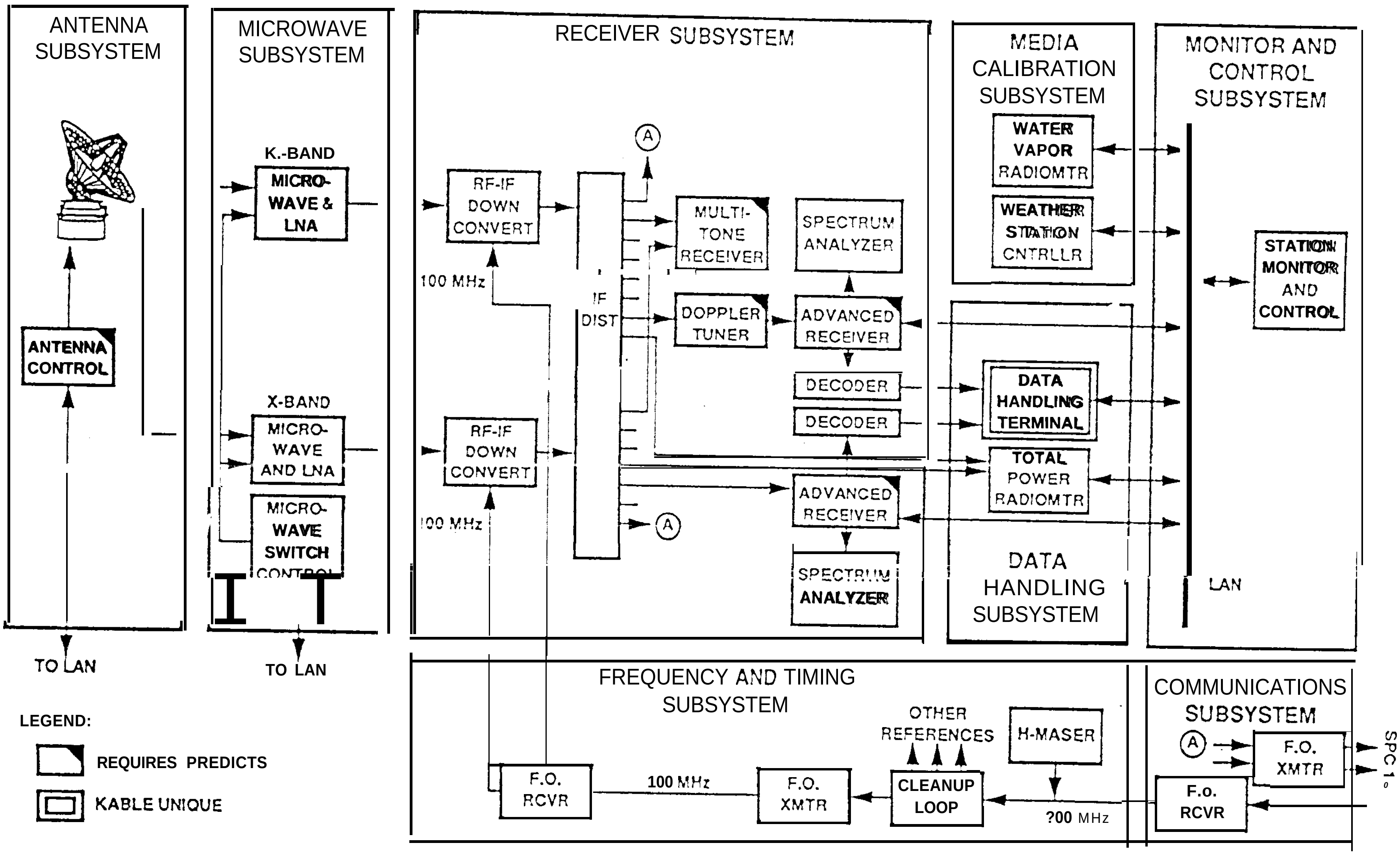
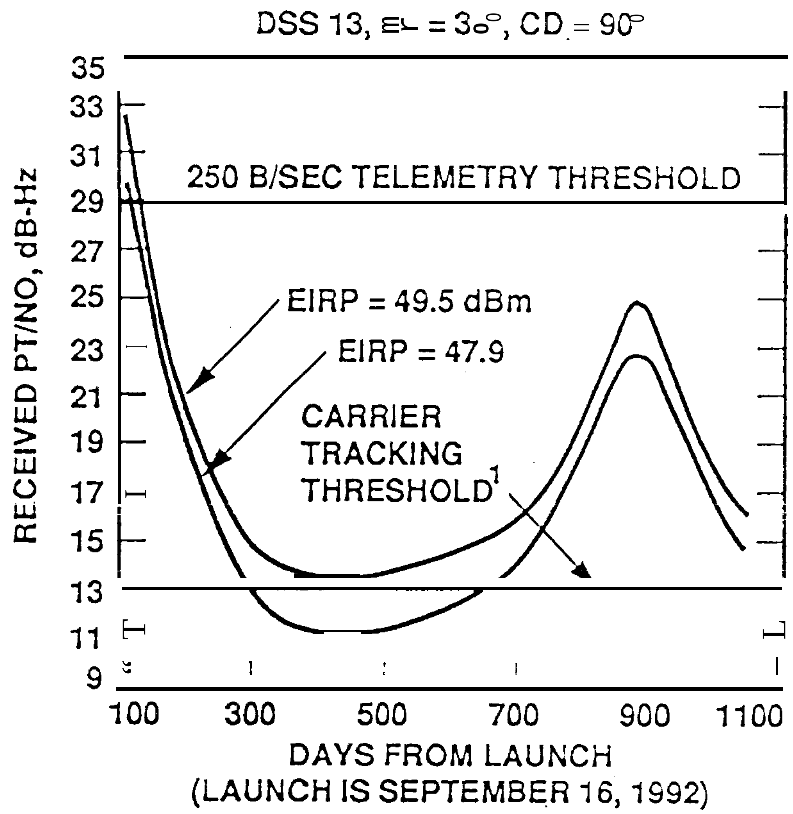
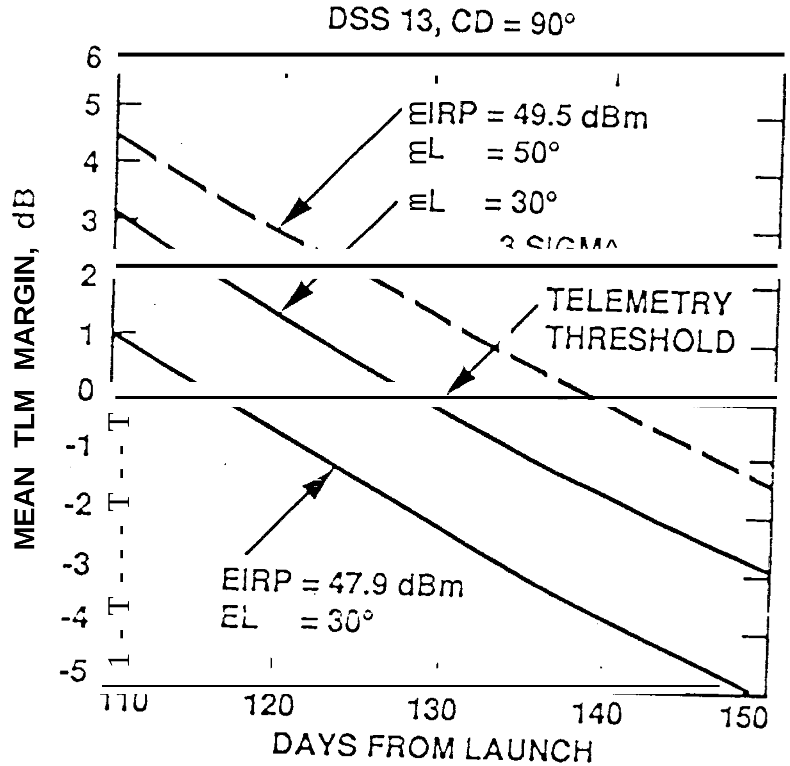


Figure 5. DSS-13 KaBLE System Diagram.



(a) Received P_T/N_0, dB-Hz



(b) Mean Telemetry Margin, dB.

Figure 6. KaBLE Kink Profile.

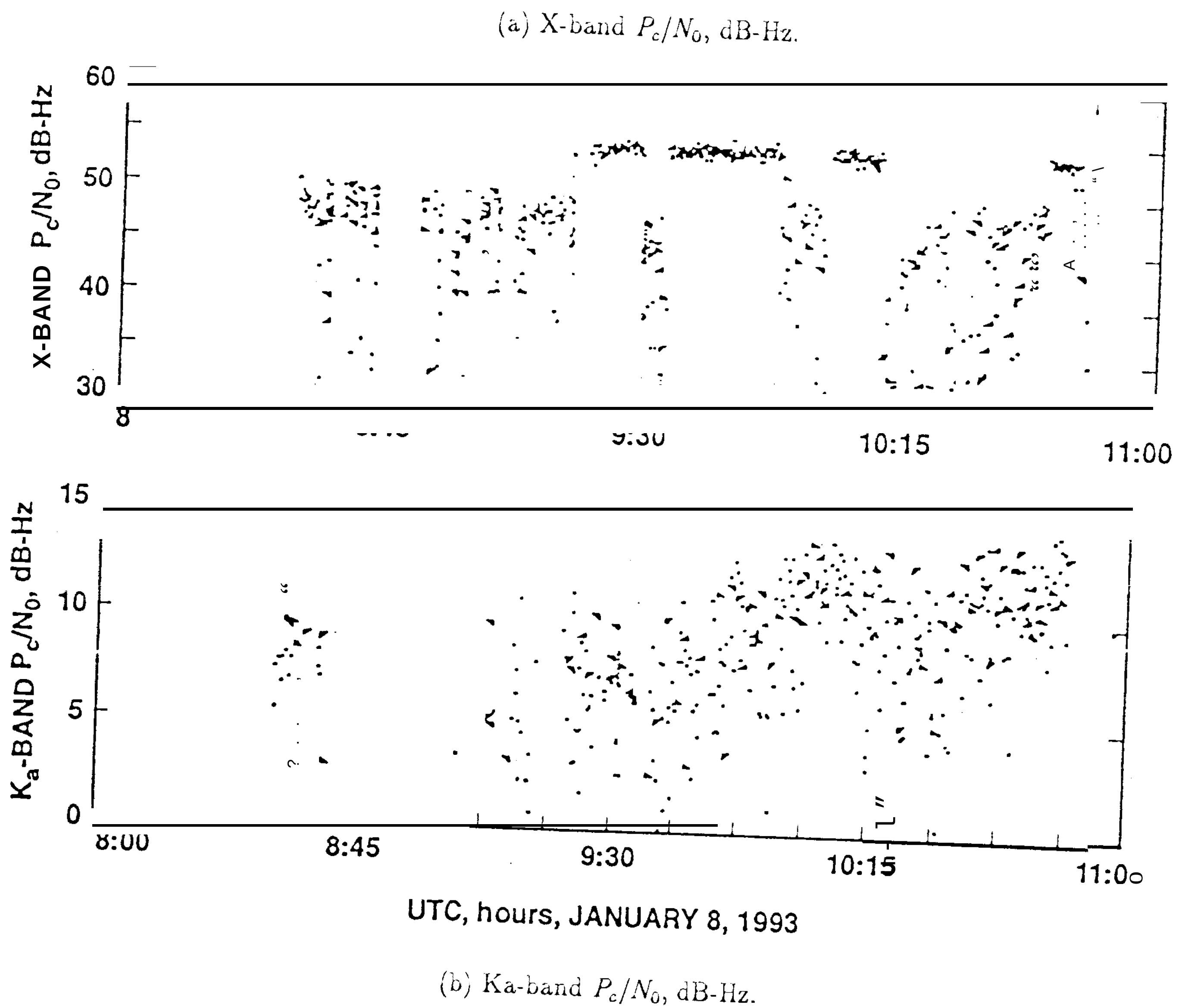


Figure 7. Received SNR of X-band and Ka-band Carrier Signal from Mars Observer.

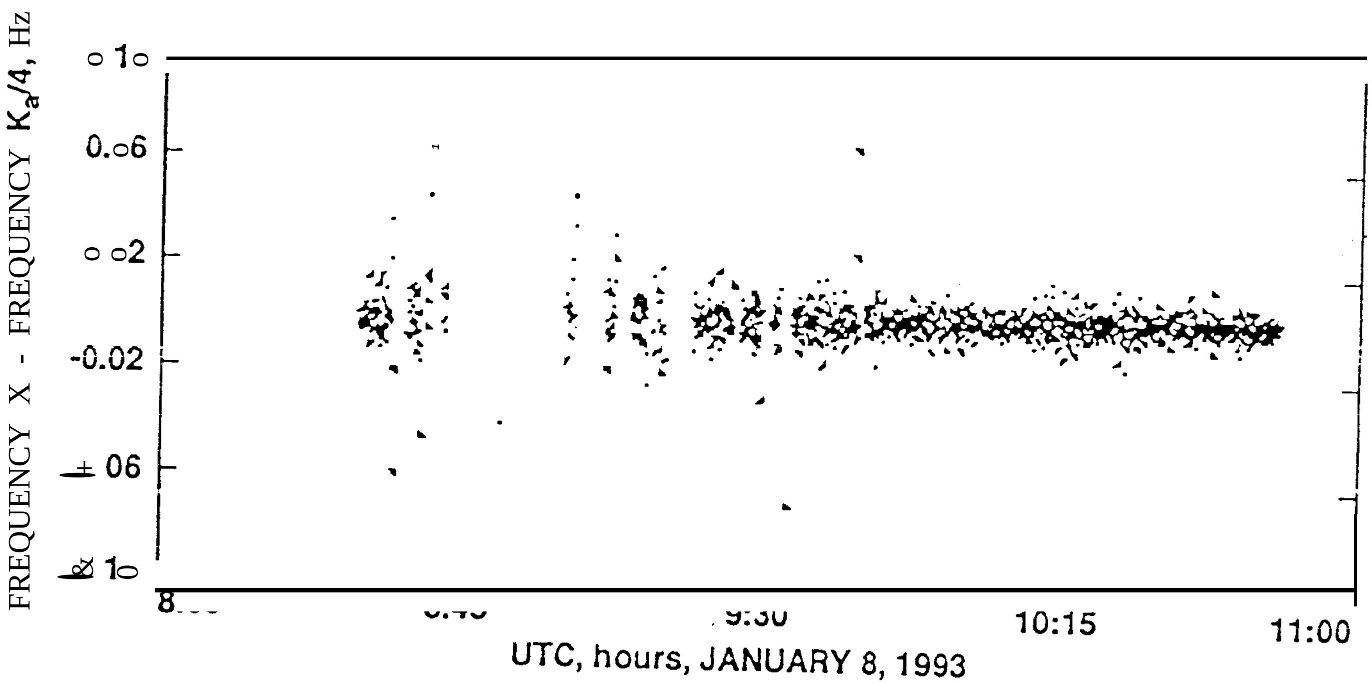
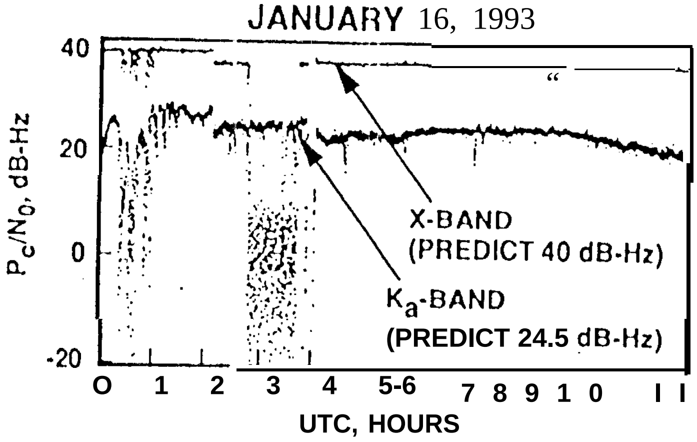
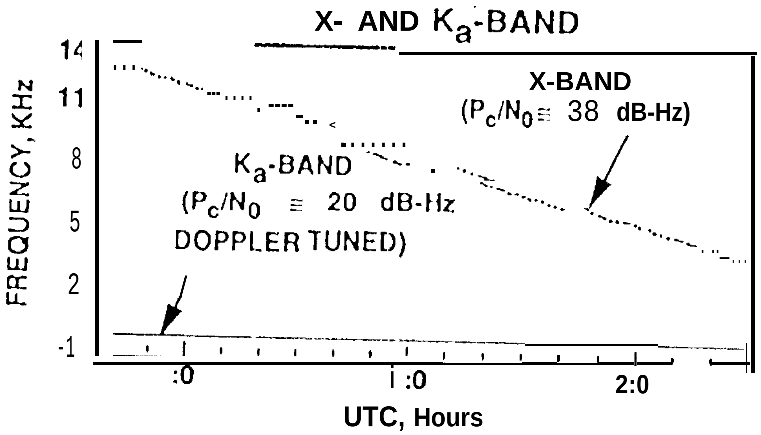


Figure 8. Difference between X-band and 1/4 Ka-band received frequencies.

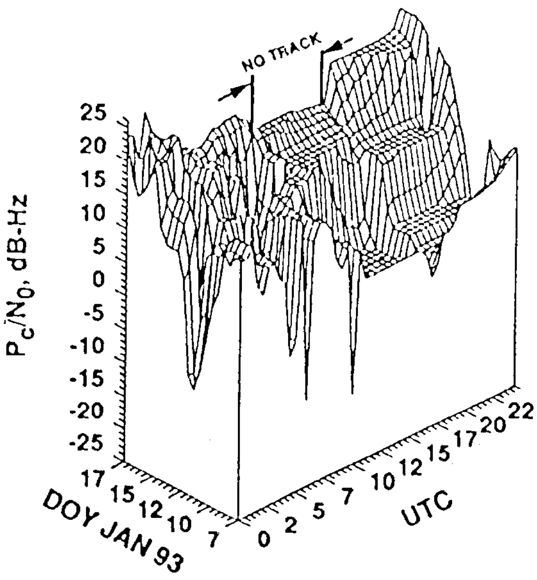


(a) Carrier P_c/N_0, dB-Hz.

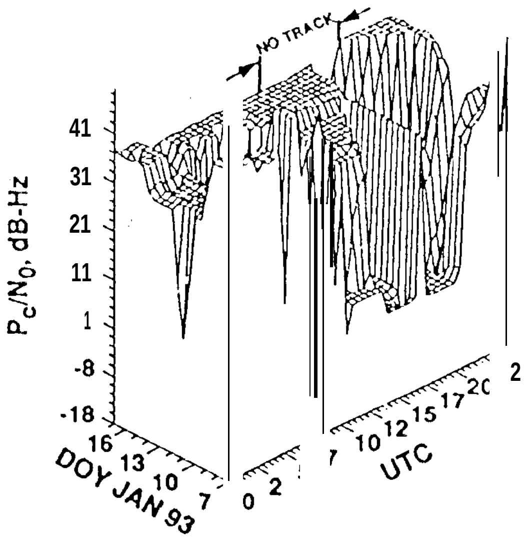


(b) Doppler tuned frequency.

Figure 9. Received signal on January 16th, 1993.

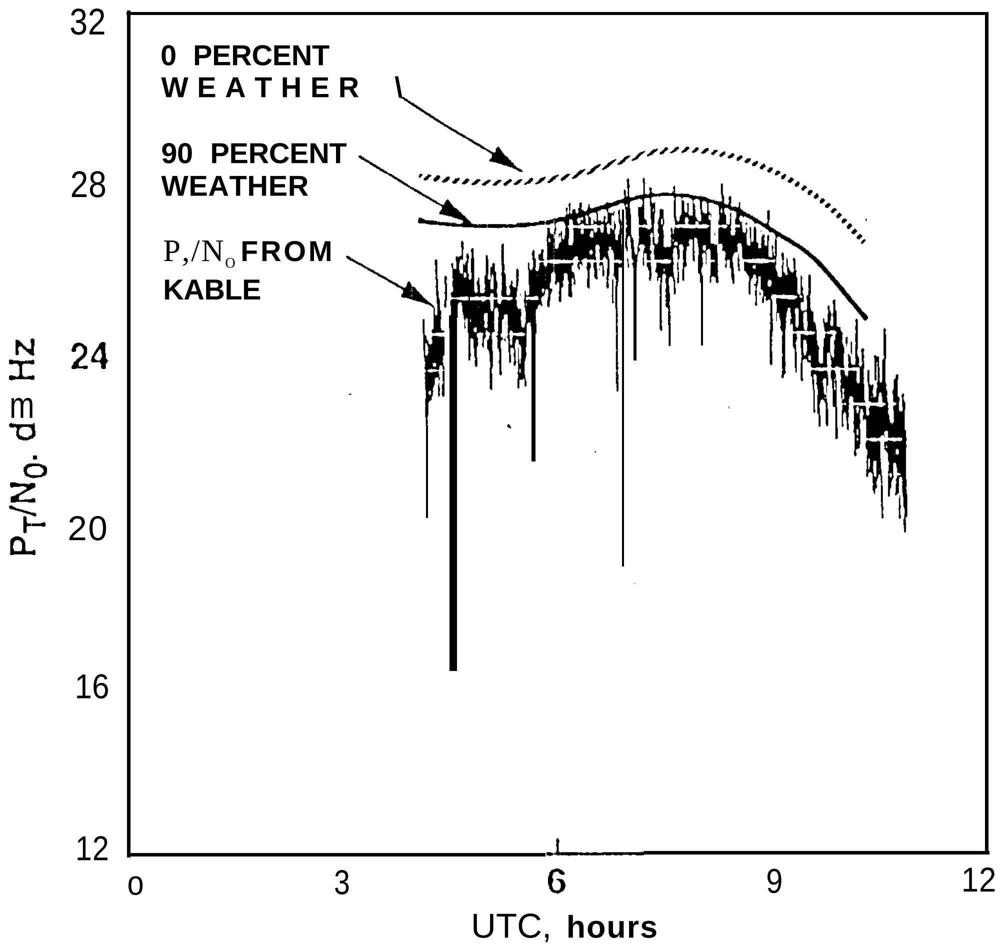


(a) Ka-band.



(b) X-band.

Figure 10. Three-dimensional plot of Carrier SNR's.



NOTE: Estimated LOSS FACTORS DUE TO SPACECRAFT POINTING, POLARIZATION AND INSTRUMENTATION BIAS HAVE BEEN REMOVED FROM THE P $_T$/N$_0$ DATA

Figure 11. Ka-band received power during telemetry demonstration.

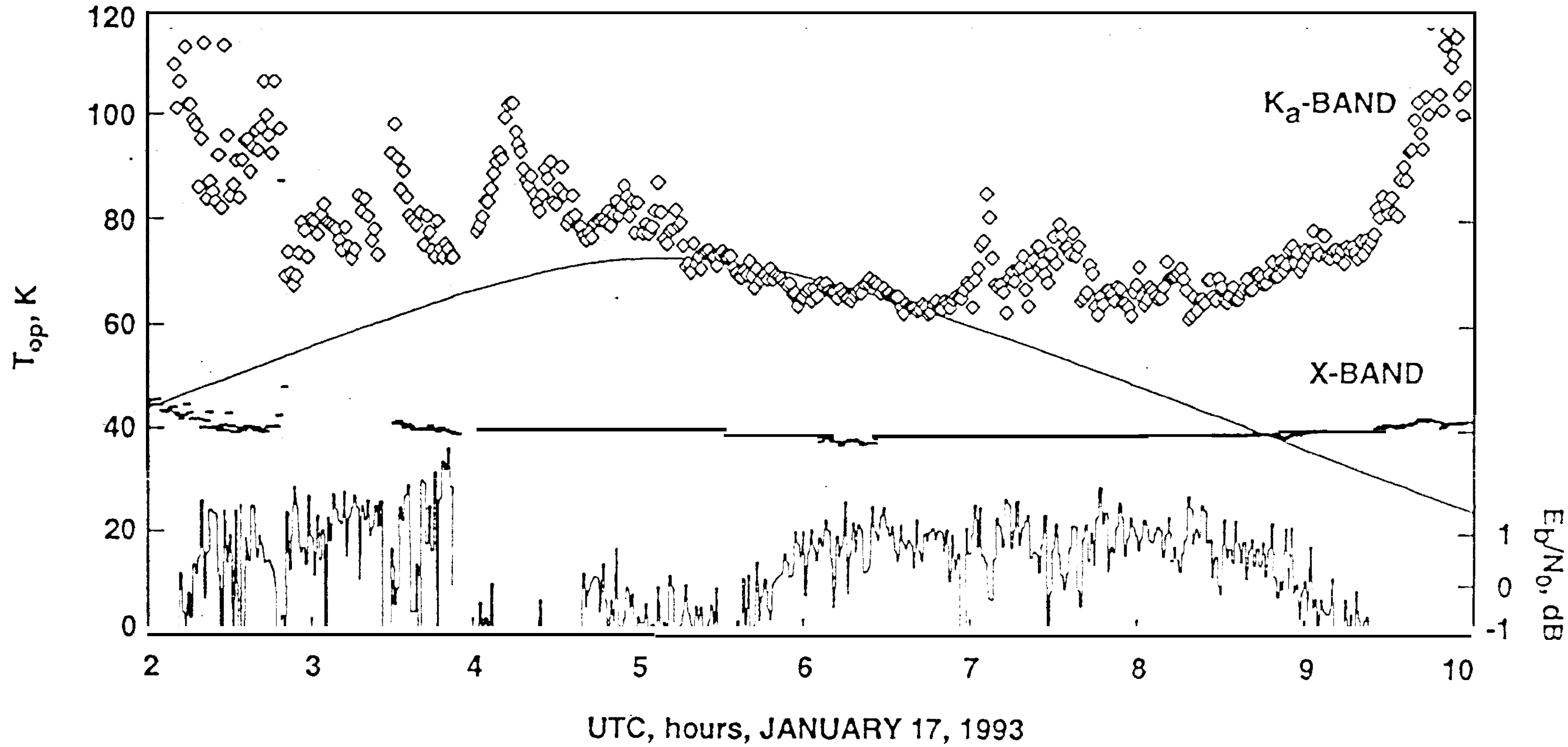
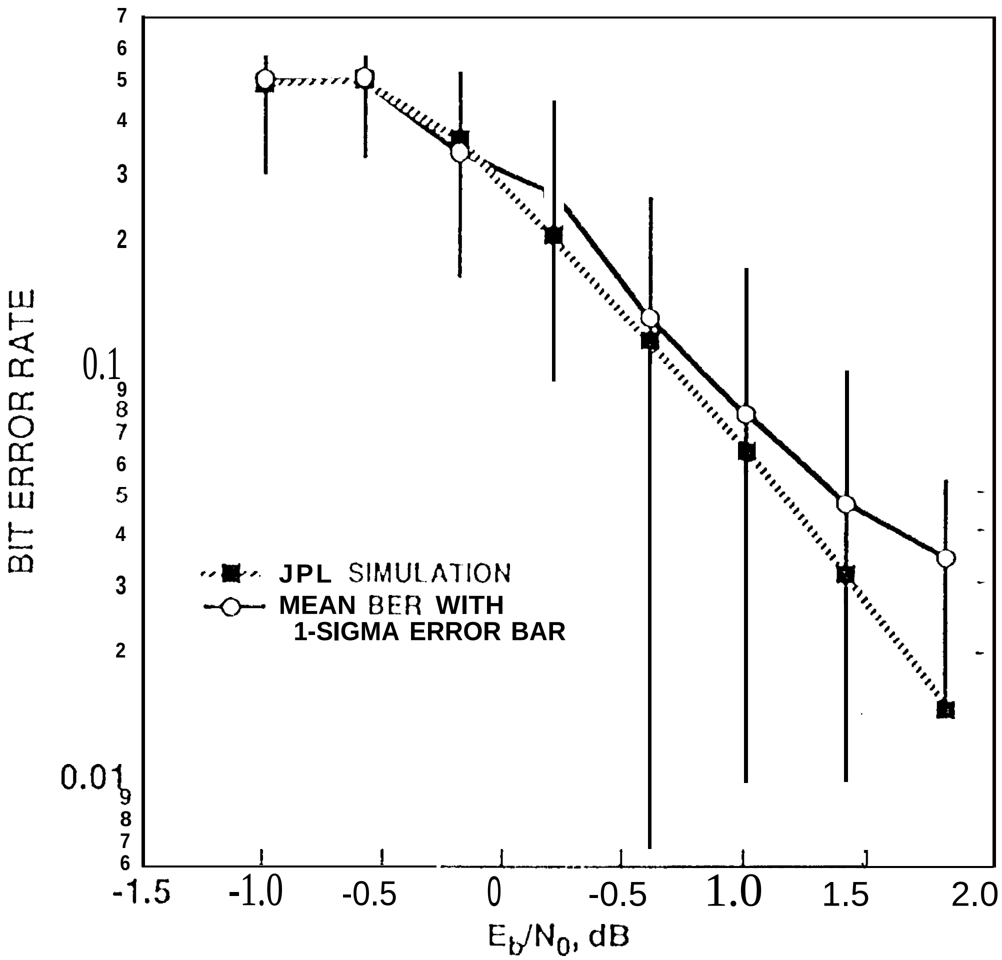


Figure 12. Ka-band E_b/N_0 and T_{op} vs. time.



NOTE: SYSTEMATIC ERRORS IN THE E_b/N_0 AS WELL AS [N THE BER DATA HAVE BEEN REMOVED

Figure 13. Ka-band telemetry decoder performance.